CONSTANT-VOLTAGE DIODE FOR OVER-VOLTAGE PROTECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a constant-voltage diode, such as a Zener diode. It also relates to a process of producing such a constant-voltage diode and to applications using such a constant-voltage diode.

Summary of the Prior Art

A constant-voltage diode, such as a Zener diode, is normally provided with a pn junction formed by n-type and p-type semiconductor regions having high impurity concentration. In order for the pn junction to have a predetermined withstand voltage, the known practice is to form a p-type guard ring region, which is deeper than the p-type semiconductor region, in peripheral parts of the pn junction when the pn junction is formed with the n-type semiconductor region and the p-type semiconductor region having a higher impurity concentration. With this technique, Zener diodes having improved reliability were said to be producable with a high production efficiency. It is also known, moreover, that the surge withstand volume can be prevented from decreasing, because of current concentration, by dividing the principal pn junction region surrounded by a guard ring region into a plurality of parts and locating these parts symmetrically, as disclosed in JP-A-57-129475. Notwithstanding this, no high- and constant-voltage diode is readily obtainable since the n-type semiconductor having high impurity concentration for attaining constant voltage and the p-type semiconductor are set adjacent each other with a constant voltage of 10 V or lower.

For a conventional high voltage diode of the type referred to above, an article by K. P. Brieger et al entitled "The Influence of Surface Charge and Bevel Angle on the Blocking Behavior of a High-Voltage p+nn+Device," IEEE Transaction on Electron Devices," VOL. ED-31, No. 6,733,)(1984) showed that the electric field intensity of the exposed surface of a pn junction is reduced by controlling the (bevel) angle intersecting the pn junction on the side edge face of a semiconductor substrate. It was suggested that a high-voltage diode could then be produced.

SUMMARY OF THE PRESENT INVENTION

The diode described in the article by K. P. Brieger et al referred to above has the disadvantage that, as the electric field intensity on the surface of the semiconductor is not consistent, the electric field tends to intensify on the surface of the n-type semiconductor adjacent the p-type semiconductor side or close to the side of the n-type semiconductor having high impurity concentration. This depends on the bevel angle, the size of the charge polarity in the protective film on the surface of the semiconductor and the like, and causing the diode to break down easily. In other words, the breakdown phenomenon would not occur uniformly at the pn junction within the element at the time the breakdown occurs but on the edge face. Even though a high- and constant-voltage diode is obtainable in such a case, the heat that may locally be generated at the time of breakdown tends to cause destruction thereof.

The known diodes described above operate on the basis of avalanche or Zener breakdown. When this is

applied to a high-voltage element, inconsistencies occur in the pn junction surface. Hence, current concentration at the time of breakdown may cause the element to fail. When such a known diode is used for a GTO thyristor as a switching element or in a snubber circuit as a protective circuit for a transistor and or an IGBT, a high spike voltage may be produced at both ends of the diode because of the inductance of the wiring. Hence, both the snubber diode and also the switching element may fail. In addition to these problems, a power converter and semiconductor elements of the power converter may fail when a high spike voltage resulting from the fluctuation of the bus voltage in the power system due to e.g. lightening is applied to the power converter.

In all the known diodes referred to above, the behavior of the diode is determined by a single pn junction. At its most general, the present invention proposes that a diode be formed with two (or more) pn junctions which are biased in the same direction by a voltage applied to the diode. Those junctions are then arranged so that they have different breakdown voltages. In this way, it is possible for the diode to be arranged so that one pn junction controls the behavior of the diode below a predetermined voltage which is less than the breakdown voltage of that junction, and above which predetermined voltage the other pn junction breaks down, via avalanche or Zener breakdown. Thus, the diode can be designed so that one pn junction breaks down at a particular reverse biasing, but the other junction is not in break-down at that reverse biasing and a stable constant-voltage diode may thus be obtained.

With the present invention, a constant-voltage diode may have three semiconductor regions of alternating conductivity type, and a fourth semiconductor region is also provided within the diode, which fourth semiconductor region is at least partially surrounded by the central semiconductor region. This fourth region is of opposite conductivity type to the central region. Normally, the fourth region adjoins one of the outer semiconductor regions, and so forms a pn junction with it. By selecting the impurity concentrations of the four semiconductor regions, it is possible for the pn junction between the fourth semiconductor region and the adjacent outer semiconductor region to have a different breakdown voltage from the pn junction (first pn junction) formed by the central and other outer region. Thus, according to a further aspect of the present invention, the impurity concentration of at least one of the fourth and adjacent outer semiconductor regions have an impurity concentration which is greater than the central and other outer semiconductor region which form the first pn junction.

It is preferable that the impurity concentration of the central region is less than both the fourth and adjacent outer semiconductor regions, and it is also preferable that the other outer semiconductor region has an impurity concentration which is less than the fourth and adjacent outer semiconductor region, as this ensures the maximum difference in behavior of the two pn junctions, but it is not essential to the present invention.

With a constant-voltage diode as described above, the behavior thereof at low reverse biasing voltages is determined by the first pn junction between the central and outer semiconductor region which is not contacted by the fourth semiconductor region. The pn junction (second pn junction) between the fourth and adjacent outer semiconductor region remains in thermal equilib-